IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re PATENT application of:

Applicant:	David Neil Payne et al.
Serial No.:	09/931,286
Filed:	August 16, 2001
For:	WDM TRANSMITTER
Art Unit:	2633
Examiner:	Hanh Phan
Docket Number:	DYOUP0222US

SUBMISSION OF PRIORITY DOCUMENT(S)

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

Regarding applicant's claim to convention priority, enclosed herewith is certified copy of the following priority application:

GB 9903880.4 filed February 19, 1999

Please acknowledge receipt of the enclosed priority document.

Respectfully submitted,

RENNER, OTTO, BOISSELLE & SKLAR

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1.	**Your reference**	P/6349.GB
2.	**Patent application number** *(The Patent Office will fill in this part)*	**9903880.4** 19 FEB 1999
3.	**Full name, address and postcode of the or of each applicant** *(underline all surnames)*	UNIVERSITY OF SOUTHAMPTON HIGHFIELD SOUTHAMPTON SO17 1BJ UNITED KINGDOM
	Patents ADP number *(if you know it)*	29867000/
	If the applicant is a corporate body, give the country/state of its incorporation	UNITED KINGDOM
4.	**Title of the invention**	OPTICAL DEVICE
5.	**Name of your agent** *(if you have one)*	D YOUNG & CO
	"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	~~21 NEW FETTER LANE LONDON EC4A 1DA~~ 120 Holborn LONDON EC1N 2DY
	Patents ADP number *(if you have one)*	59006

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Country	Priority application number *(if you know it)*	Date of filing *(day/month/year)*
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7. **If this application is divided or otherwise derived from an earlier UK application, give the number and filing date of the earlier application**

Number of earlier application	Date of filing *(day/month/year)*

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Priority documents	0
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Request for substantive examination *(Patents Form 10/77)*	0
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D YOUNG & CO
Agents for the Applicants

Date

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12. **Name and daytime telephone number of the person to contact in the United Kingdom**

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OPTICAL DEVICE

Optical fibre telecommunication systems are undergoing continual expansion, fuelled by the need for more bandwidth. The nature of the expansion in demand for bandwidth is such that wavelength division multiplexing (WDM) of optical channels is required to overcome the bottleneck in capacity which arises in time-division-multiplexed (TDM), single-wavelength systems due to speed limitations of electronic circuits. State-of-the-art commercial systems use up to sixteen simultaneous channels to increase system capacity but the demand for capacity will continue to increase. Although the capacity of the third telecommunications window is very large, loss limitations dictate that optical amplifiers are essential building blocks in modern networks and optical amplifiers, in particular erbium-doped fibre amplifiers (EDFA), determine the currently available practical bandwidth. Current trends are towards dense wavelength division multiplexing with a 100GHz channel spacing as the next generation of WDM comb standards. Recent experiments have demonstrated 1Tb/s transmission using 100x10Gb/s [1] and 50x20Gb/s [2] WDM channels over 400km and 600km, respectively.

There are two alternative approaches to implement high quality sources for telecommunication purposes, namely the semiconductor and the fibre distributed-feedback (DFB) laser. Commercial systems and most experimental systems being studied so far [1] [2] use various types of semiconductor lasers (SLs) as sources, for example DFB or DBR lasers. SLs are powered individually and are usually wavelength-stabilised (in order to meet the stringent telecom grid requirements) by the use of an external cavity. It is also well known that SLs are prone to aging effects and sudden failures resulting in a complete loss of the corresponding communication channel. This renders SLs quite unsuitable for integration, since failure of a single laser implies replacement of the entire integrated chip. First developed at Southampton University [3], fibre DFBs have been studied for the last few years and have potential advantages in terms of wavelength setability and stability, as well as reliability, longevity and cost, such that they appear as a promising alternative to semiconductor laser sources. In addition and most importantly, there is no known degradation and failure mechanism for fibre or waveguide DFB lasers. Fibre and waveguide DFB lasers, though, still rely on high power semiconductor lasers for efficient

pumping and large output powers. Semiconductor pump lasers, however, can be appropriately multiplexed, using standard NxN multiplexing techniques, to power an array of fibre DFB lasers [4]. In this case, each fibre DFB laser is equally fed by all pump lasers and, therefore, failure of an individual pump will only uniformly reduce the pumping level on each DFB without any catastrophic effect.

Viewed from one aspect the invention provides an optical device that addresses at least some of the above described problems.

In the following we disclose a fully integrated transmitter module for DWDM applications. Figure 1 shows schematically the general configuration of the proposed module. M pump lasers (stage#1) are multiplexed by an MxN coupler (stage#2) and used to feed an array of N optically pumped lasers emitting at wavelengths $\lambda_1, \lambda_2, \ldots \lambda_N$ (stage#3). The parameter M determines the number of pump lasers as well as the number of inputs of the pump-multiplexing coupler and can be smaller or equal to parameter N that determines the number of optically pumped lasers. The laser outputs can be passed through isolators (stage#4) before entering the next section (stage#5) were they are monolithically modulated. The outputs of the modulators are passed through an array of tunable attenuators (stage#6). Finally all the individual channel outputs are recombined into a single output in stage#7.

Stage#1 comprises M pump lasers that can be electrically or optically driven. The parameter M can be larger or equal to 2. The pump lasers emit at any appropriate wavelength and power level to optically pump the laser cavities of stage#3. As an example, appropriate pumping wavelengths can be in the regions of 980nm, 1060nm, 1480nm, to mention a few.

The MxN multiplexer (stage#2) can be any composite coupled-waveguide or fibre structure that splits any of the M inputs equally into any of the N outputs. As already mentioned, M is smaller or equal to N. The pump multiplexers can be based on single NxN fused (or multimode) couplers, or concatenated 2x2 couplers (50:50 at the pump wavelength). The couplers can be in fibre or planar waveguide form. Another example of pump multiplexer is the arrayed waveguide

grating (AWG) which is particularly attractive for large M. Typical values of N is 2, 4, 8, 16...256...

The optically-pumped laser section (stage#3) will comprise of N fully thermally-stabilised and optimised individual single-polarisation fibre or waveguide DFB or DBR lasers. Fibre or waveguide DFBs can be fabricated in a material doped with an appropriate rare earth that provides sufficent gain over a certain bandwidth anywhere within the 800nm to 1900nm range. Er^{3+} and $Er^{3+}/Yb^{3+}$are two examples of such appropriate dopants that provide gain at the 1550nm window. The optically pumped lasers can also be based on semiconductor technology.

The isolator array (stage#4) is introduced to eliminate feedback due to fibre splices or waveguide refractive-index/modal-field mismatches or Rayleigh backscattering and avoid laser output frequency and power instabilities.

For the modulation of the optical signal in stage#5, a number of different modulators can be used, such as LiNO3 modulators or chi(2)-based electro-optic modulators. In stage#6 the individual channels are passed through an array of N variable optical attenuators that are used to adjust their output powers. The optical attenuators can be electrically or optically controlled by tapping out and monitoring a small portion of their output. The variable optical attenuator array can be used to either equalise the optical powers or adjust them appropriately (pre-emphasis) before launching them into an amplified optical link. The attenuator array can be alternatively inserted between stages#3 and #4 or #4 and #5. In stage#7, all the modulated and properly adjusted channel outputs are recombined into a single output for launching into the optical network. The recombiner circuitry can be based on planar waveguide or fibre optical technology.

If we define as *pump redundancy* the amount of relative pump reduction (in %) when one of the pump lasers fails, it can be easily realised thet the proposed MxN ($M \leq N$) pump multiplexer, in Figure 1, can provide (1/M)% pump redundancy. In most telecom applications, a pump redundancy of ~10% will usually suffice. For $M \geq 16$, it is obvious that the proposed MxN pump multiplexer provides excessive pump redundancy. On the other hand, for $M \geq 16$ the complexity

of or the number of components required for the pump multiplexer increases dramatically and renders the implementation of such device either impractical or impossible or extremely expensive. To ease the design, improve the performance or reduce the cost of the pump multiplexer (stage#2), we propose a different approach that is shown schematically in Figure 2. The pump redundancy is applied in n blocks of Mi pumps, where Mi (i=1,2..n) < M and M1+M2+...+Mn = M. Each block of Mi (i=1,2,..n) pumps is feeding a block of Ni (i=1,2...n) optically pumped lasers, where Ni (i=1,2..n) < N and N1+N2+...+Nn = N, through a Mi x Ni pump multiplexer. In this case the overall pump redundancy provided by the multiplexer is (1/Mp)%, where Mp is the minimum Mi. The rest of the stages are the same as Figure 1.

As an example of the complexity reduction provided by the scheme of Figure 2, let us consider two different implementations of a 128x128 pump multiplexer. If the NxN multiplexer (where $N=2^m$) is comprised of concatenated 2x2 couplers, it can be easily shown that the total number of required couplers is $C = m \cdot 2^{m-1}$. In the configuration of Figure 1, $M=N=2^7$, (m=7) and therefore the number of required couplers is $7x2^6 = 448$!!!. The pump redundancy in this case is 0.008%. However, the total splice and radiation losses will make this very expensive solution impractical. If on the other hand we adopt the strategy of Figure 2 instead and divide the pump multiplexing unit in 16 blocks of 8 inputs each, then M1=M2=...M16=8 and the total number of couplers is reduced to $16x(3x2^2)=16x12=192$. Each block involves only 12 couplers and therefore shows massively reduced insertion loss. Such an approach not only halfs the cost of the unit, but also reduces the insertion loss to very small levels. The pump redundancy in this case is ~12%, very close to the 10% target. Adoption of the same strategy in planar waveguide, or AWG based multiplexers will result in similar benefits.

Stages #1 to #6, in Figures 1 and 2, can be either separate units connected optically together or they can be combined into integrated subgroups connected together. Each subgroup can contain two or more of the aforementioned stages. They can also all be integrated on a single all-planar or hybrid waveguide chip to produce a fully integrated and robust transmitter module. The integrated chip can be based on glass or LiNO3 technology or any other appropriate integrated optics technology. In the case that all stages are fully integrated in one chip or stages #3, #5, #6

and #7 constitute the only fully integrated subgroup, the isolator array (stage#4) can be ignored and replaced with a single isolator at the combined output of the integrated transmitter (to avoid the deleterious effects of Rayleigh back-scattering produced by the fibre-optic link). The transmitter topologies (Figure 1 and 2) disclosed here require each optically-pumped-laser output being on a separate fibre or waveguide so that it can be easily interfaced with the optical modulator. The laser array is fully protected from backreflections by the intervened isolators. A single pump can be used to pump a number of lasers by splitting the pump output and distributing it to a number of optically pumped lasers. Reliability of the module is an important issue, and this can be improved by multiplexing and splitting a number of pump lasers and distributing the power to the optically pumped lasers. The loss of a single pump laser will then not cause the loss of any channels. The drive currents of the remaining pump lasers could be increased to compensate for the lost laser, if sufficient margin has been built in, until the failed unit is replaced. The wavelength separation of the optically pumped lasers can be designed with flexibility but it is proposed to generate a 100GHz optical comb or any other comb compatible with the ITU grid. All laser outputs, after being modulated, are recombined into one output so that they can all be launched into the optical communication network.

Example of Integrated 16-Channel WDM Transmitter

Figure 3 shows an example of the proposed Integrated 16-channel WDM Transmitter that uses eight 980nm pump lasers (stage#1). The pump redundancy scheme (stage#2) comprises an 8x16 all fibre star coupler consisting of 24 2x2 fibre couplers (50:50@980nm). Stage#3 constists of 16 single-polarisation, unidirectional fibre DFB high power lasers at 1550nm. Stage#4 includes 16 pigtailed fibre isolators. Stage#6 is an all fibre multiplexer comprised of 15 2x2 fibre couplers (50:50@1550nm). The optical modulators (stage#5) and optical attenuator (stage#7) arrays have been ignored in this example. It should, however, be stressed that the pump unit (stage#1) includes an additional WDM coupler (980/1550nm) infront of each pump source in order to filter out the residual laser power (at 1550nm) that leaks out the back-end of the DFB lasers and propagates in the backward direction.

Integrated WDM Transmitter with feedback control

The pump redundancy scheme (stage#2) in Figure1, ensures that any pump power reduction, due to one or more pump failures, is equally distributed among theoptically pumped laser array (stage#3). In this case, the laser output powers are reduced by the same amount. Therefore, if the output power of one of the optically pumped lasers is monitored, as shown in Figure 4, the electrical power of the active pump lasers is adjusted to restore the fibre laser output powers (until the faulty pump(s) is(are) replased). Similar feedback control can be employed in the pump redundancy scheme of Figure 2. In this case at least one laser corresponding to each block should be monitored and only the affected block of pumps is abjusted. In both cases, the feedback can be provided by the variable attenuator feedback circuitry.

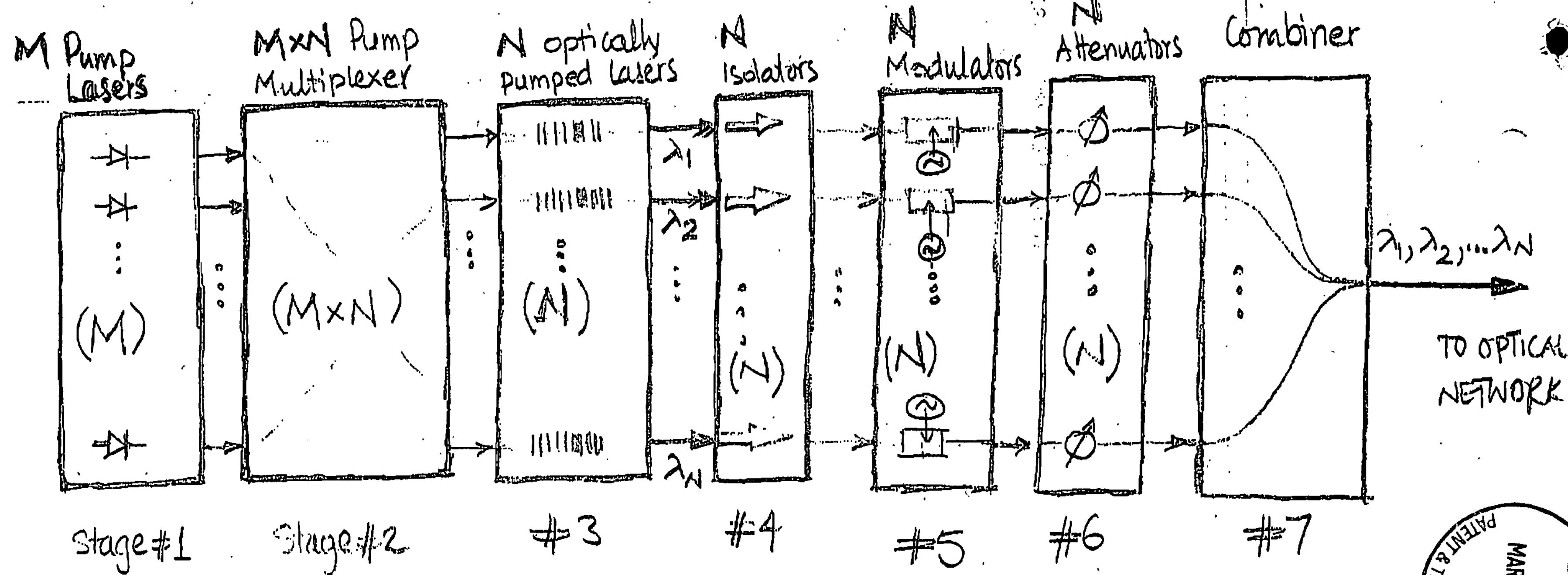
References:

[1] A. K. Srivastava et al., "1Tb/s transmission of 100 WDM 10Gb/s channels over 400km of TrueWave™ fiber", in *OFC '98 Technical Digest*, paper PD10, 1998.

[2] S. Aisawa, T. Sakamoto, M. Fukui, J. Kani, M. Jinno and K. Oguchi, "Ultra-wide band, long distance WDM transmission demonstration: 1Tb/s (50x20Gb/s), 600km transmission using 1550 and 1580nm wavelength bands", in *OFC '98 Technical Digest*, paper PD11, 1998.

[3] J. T. Kringlebotn, J.-L. Archambault, L. Reekie and D. N. Payne: 'Er^{3+}:Yb^{3+}-codoped fibre distributed-feedback laser', *Optics Letters*, 19(24), 2101-3, Dec 1994.

[4] W. H. Loh, B. N. Samson, L. Dong, G. J. Cowle and K. Hsu, "High performance single frequency fibre grating-based erbium:ytterbium-codoped fibre lasers", J. Lightwave Technology, vol. 16, no. 1, pp. 114-118 (1998).



M Pump Lasers
MxN Pump Multiplexer
N optically pumped Lasers
N Isolators
N Modulators
N Attenuators
Combiner
(M)
(MxN)
(N)
(N)
(N)
(N)
λ_1
λ_2
λ_N
$\lambda_1, \lambda_2, \ldots \lambda_N$
TO OPTICAL NETWORK
Stage#1
Stage#2
#3
#4
#5
#6
#7

Figure 1

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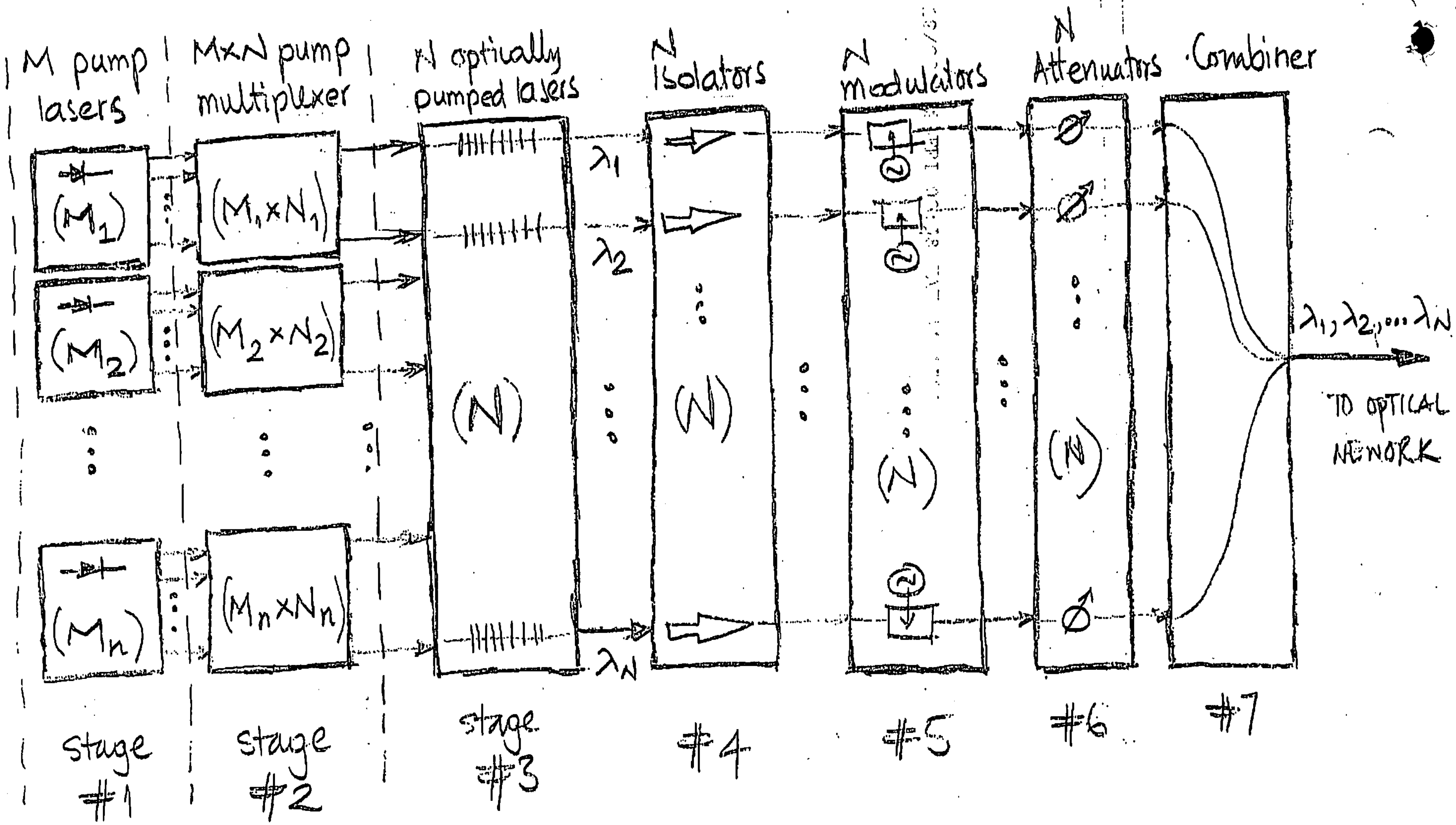


$M_1 + M_2 + \dots M_n = M$

$N_1 + N_2 + \dots N_n = N$

Figure 2

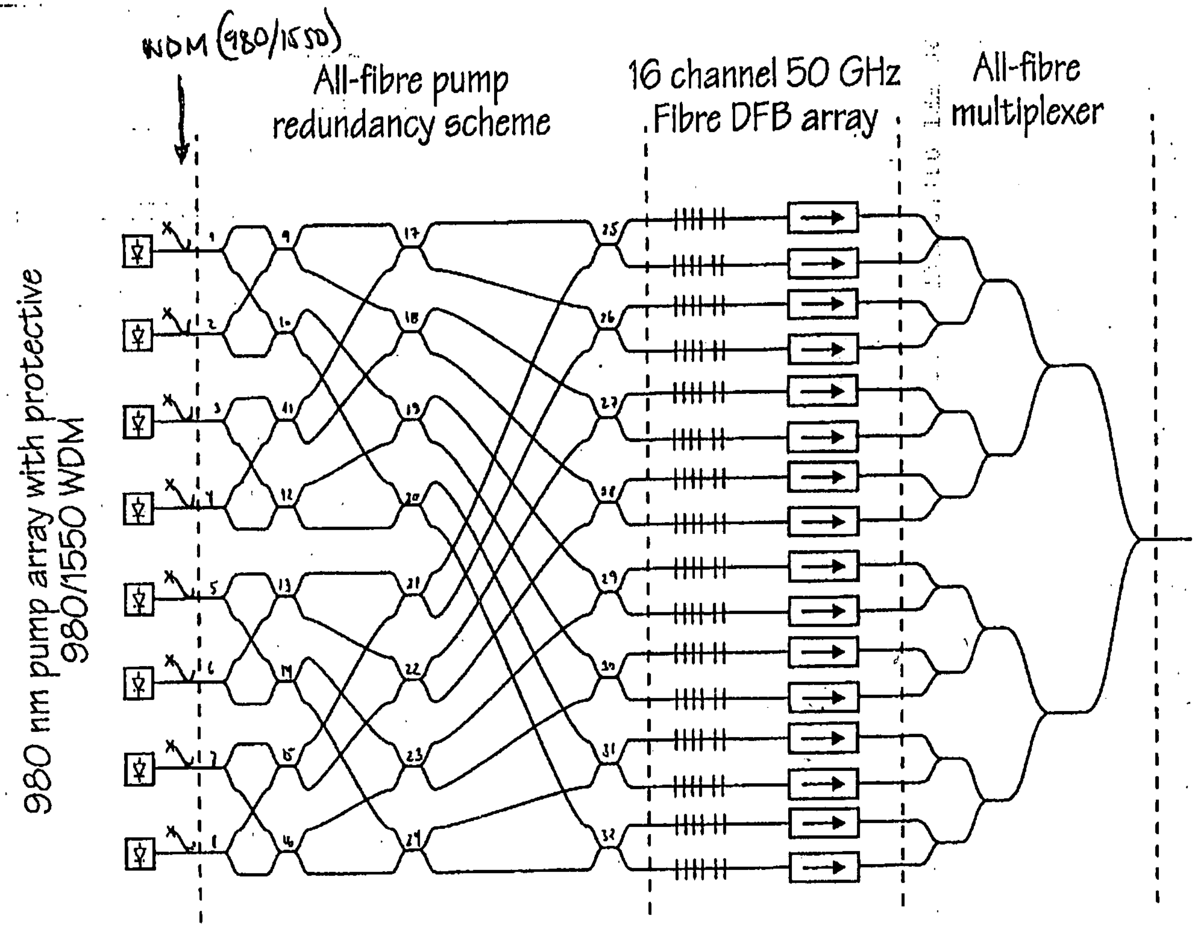
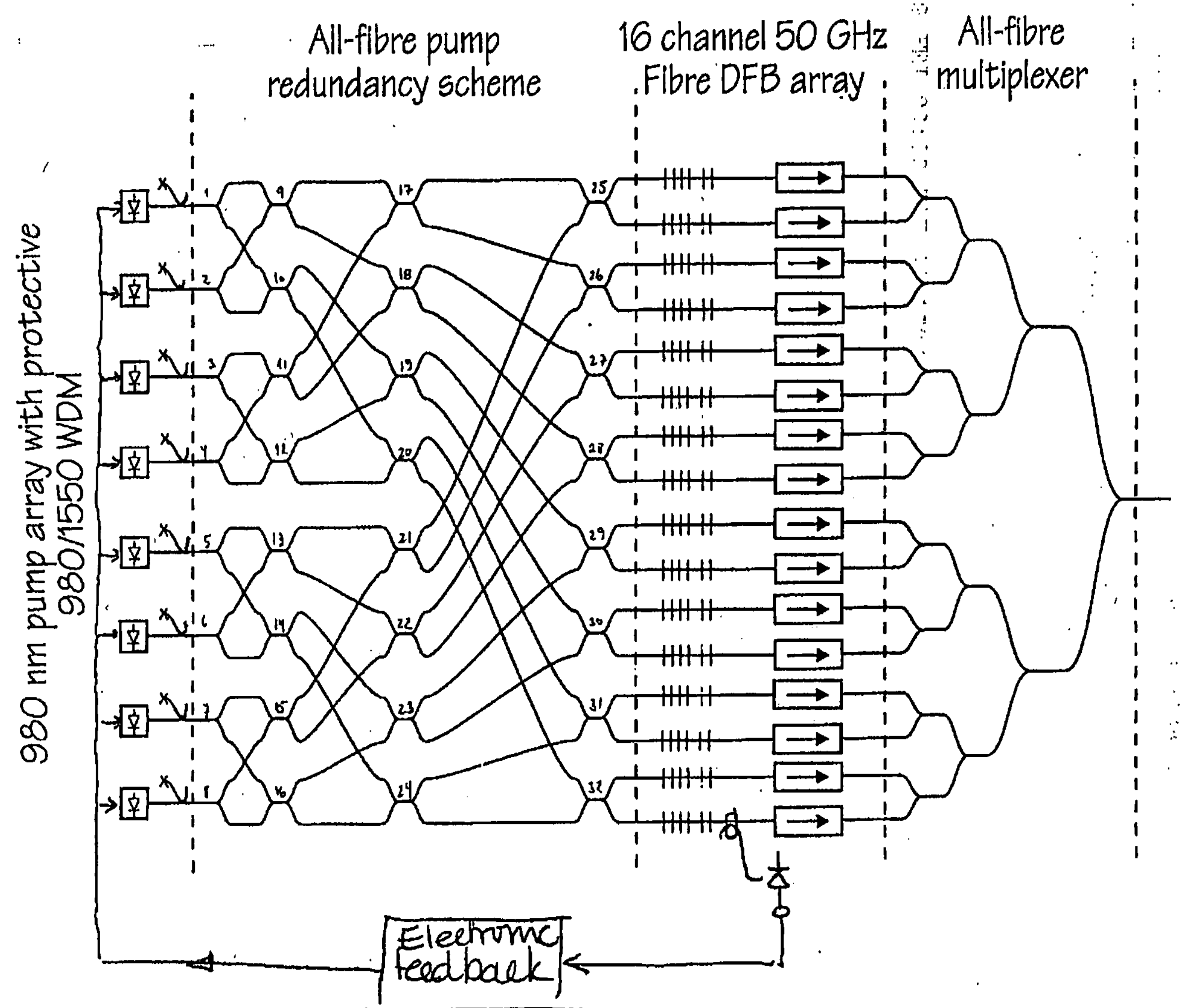

WDM (980/1550)
All-fibre pump
redundancy scheme
16 channel 50 GHz
Fibre DFB array
All-fibre
multiplexer
980 nm pump array with protective
980/1550 WDM

Figure 3



All-fibre pump redundancy scheme
16 channel 50 GHz Fibre DFB array
All-fibre multiplexer
980 nm pump array with protective 980/1550 WDM
Electronic feedback

figure 4